Deaf learners frequently demonstrate significantly less vocabulary knowledge than hearing age-mates. Studies involving other domains of knowledge, and perhaps deaf learners’ academic performance, indicate similar lags with regard to world knowledge. Such gaps often are attributed to limitations on deaf children’s incidental learning by virtue of not having access to the conversations of others. Cochlear implants (CIs) have been described as providing such access, and rapid growth in vocabularies following pediatric cochlear implantation has suggested that, over time, children with implants might close the gap relative to hearing peers. Two experiments evaluated this possibility through the assessment of word and world knowledge among deaf college students with and without CIs and a hearing comparison group. Results across essentially all tasks indicated hearing students to outperform deaf students both with and without CIs with no significant differences between the latter two groups. Separate analyses of a subset of implant users who received their implants at a young age did not reveal any long-term advantages, nor was age of implantation related to enhanced performance on any of the tasks. Results are discussed in terms of incidental learning and the accessibility of word and world knowledge to deaf learners with and without CIs.

This study concerns the incidental learning of word and world knowledge by deaf learners, some of whom have greater access to spoken language in the environment through the use of cochlear implants (CIs). Language comprehension, whether via print or through the air (spoken or signed language), is a complex skill that draws on a variety of cognitive abilities and knowledge, some specific to language and literacy and others of a more general nature. Hirsch (2003) emphasized that with regard to reading, vocabulary and world knowledge build on each other and together facilitate deeper reading comprehension (Jackson, Paul, & Smith, 1997; Moog & Geers, 2003). This is just as true for through-the-air communication as it is for reading. With regard to vocabulary in particular, although some is taught explicitly, Hirsch (p. 16) noted that “Most vocabulary growth results incidentally, from massive immersion in the world of language and knowledge” (see also Cawthon, 2011; Neuman & Koskinen, 1992; Van Zeeland & Schmitt, 2013; Vidal, 2011). As a result of their limited access to full, fluent language, however, many if not most deaf and hard-of-hearing (DHH) learners display lower levels of vocabulary compared to hearing peers (Qi & Mitchell, 2012). Indeed, the relative inaccessibility of incidental learning through overhearing the language of others is perhaps the most frequent explanation offered for their language, academic, cognitive, and social delays (Bull, 2008; Calderon & Greenberg, 2011; Hintermair, 2014; Kritzer, 2008; Marschark, Shaver, Nagle, & Newman, in press). Overcoming that barrier is one of the most frequently espoused benefits of pediatric CIs (James, Rajput, Brinton, & Goswami, 2008; McConkey Robbins, 2006; Stith & Drasgow, 2005).

World Knowledge and Deaf Learners

Although there have been numerous studies documenting young DHH children’s limited vocabularies (see Luckner & Cooke, 2010, for a review), less is known...
about their knowledge of the world or the vocabularies and world knowledge of older deaf learners. Evans (1988) discussed deaf children’s lack of world knowledge, and sociocultural knowledge in particular, in terms of language deprivation. However, his explanation for the situation was based on the mistaken belief that sign language limits the potential of deaf children to acquire such knowledge because it is concrete and literal (pp. 239–240). Cawthon (2011), in contrast, noted that even if sign language skills at lexical and syntactic levels do not transfer directly to reading—the most frequent and rich source of world knowledge—the ability to make inferences and make connections with world knowledge likely do.

Morere (2013a) examined the world knowledge of DHH college students. In her sample, over 97% of the participants reported knowing American Sign Language (ASL), over 90% indicated it as their language preference, and a majority indicated that while they were growing up, at least one parent used sign language well enough to communicate with them “fully and effectively” (Allen & Morere, 2013; p. 29). World knowledge was examined through use of the Woodcock–Johnson III Reading Fluency subtest (Woodcock, McGrew, & Mather, 2001). That test normally requires participants to read a series of brief sentences and indicate whether or not they are correct, based on knowledge of the world (e.g., “All cats have slimy fur”). In Morere’s study, the sentences were presented via signed English. She found that the participants’ mean score (99.87) did not differ from the mean of 100 in the age-based norms, but scores ranged from 70 to 131 and were “below expectations for college students” (p. 110). Most importantly from an educational perspective, that large range of scores reflects the considerable variability among DHH students in a variety of academic and nonacademic domains (Knoors & Marschark, 2014, ch. 6). The variability in Morere’s sample was further reflected in students’ scores on the Woodcock–Johnson III Academic Knowledge subtest (Woodcock et al., 2001), which measures knowledge across several domains relevant to this study and includes social studies, humanities, and science subtests. On that test, Morere’s DHH college students obtained a mean score (84.32), one standard deviation below the age-based norms with a range of 63–116. She concluded that “student performance on the Academic Knowledge test is quite low, indicating gaps in Academic Knowledge for this population of students” (p. 135). Morere found that Academic Knowledge scores were highly related to various measures of reading ability. They also were related to speechreading skill but not to sign language skill, suggesting the possibility that spoken language may be a greater (incidental) source of world knowledge than sign language (Evans, 1988) and again highlighting a potential advantage of CIs.

Word Knowledge and Deaf Learners

More studies have examined DHH learners’ word knowledge than their world knowledge. Many of those studies have involved versions of the Peabody Picture Vocabulary Test (PPVT) in examinations of language growth among deaf children. Moeller (2000), for example, found that earlier intervention services for deaf infants and toddlers were associated with higher scores on the PPVT-Revised (Dunn & Dunn, 1981) among 5-year-olds. Scores were unrelated to hearing thresholds, but significantly correlated with nonverbal intelligence. Stelmachowicz, Pittman, Hoover, and Lewis (2004) used the PPVT-III (Dunn & Dunn, 1997) in a study of novel word learning with 6- to 9-year-old deaf and hearing children. The deaf children scored below hearing peers on both the PPVT and a novel word learning task, but a steeper slope in the regression line relating the deaf children’s PPVT scores and age suggested to the authors that with effective amplification, vocabulary growth of deaf children might catch up to that of hearing peers as they get older (p. 52). Radić, Bradarić Jončić, and Farago (2008), however, administered the PPVT-III to groups of older deaf and hearing Croatian students, aged 15–21 years. Consistent with previous results, the deaf students’ mean scores were relatively low, at the level of hearing 10-year-olds. Finally, Sarchet, Marschark, Borgna, Convertino, Sapere, and Dirmyer (2014) used the PPVT-4 (Dunn & Dunn, 2007) to examine the vocabulary knowledge of hearing college students and deaf peers, both those who used sign language and those who used spoken language, as it related to print exposure, communication backgrounds, and reading and verbal abilities. PPVT scores were significantly related to reading and verbal
abilities for both groups, but the hearing students demonstrated significantly larger vocabularies than the deaf students. Among the deaf students, PPVT scores were positively related to self-reports of spoken language ability and negatively related to self-reports of sign language ability. Using a pretest in which students indicated which of the PPVT words they (thought they) knew, Sarchet et al. found that DHH students significantly overestimated their vocabulary knowledge relative to their hearing peers.

Taken together, the research described above is consistent with the frequent claim that DHH learners face real challenges in acquiring word and world knowledge via incidental learning (Hirsch, 2003; Van Zeeland & Schmitt, 2013; Vidal, 2011). Central to this issue is the fact that approximately 95% of deaf children have hearing parents, the vast majority of whom are not fluent users of sign language. As a result, their children frequently do not have access to fluent language models. In recent years, however, digital hearing aids and CIs have provided many deaf children with better hearing and greater access to spoken language, resulting in some rethinking about educational methods for deaf learners (Knoors & Marschark, 2012).

Cochlear Implants, Word Knowledge, and World Knowledge

Cochlear implants are multifrequency electrodes surgically implanted near the auditory nerve, with an external microprocessor worn like a hearing aid that is mapped to the specific frequencies of an individual’s hearing loss. With more deaf students effectively using spoken language than ever before, our understanding of and methodologies in raising and educating deaf children are changing as well. As noted earlier, one popular assumption in that regard is that CIs offer a means by which deaf children should be able to acquire more word and world knowledge incidentally (James et al., 2008; McConkey Robbins, 2006; Stith & Drasgow, 2005). The extent to which this actually occurs, however, is difficult to ascertain.

Both age at implantation and length of implant use have been found related to various measures of speech, language, and literacy, including vocabulary (Connor, Hieber, Arts, & Zwolan, 2000; Dillon, De Jong, & Pisoni, 2012; Tye-Murray, Spencer, & Woodworth, 1995). Tye-Murray et al. (1995), for example, found that children who received their implants prior to 5 years of age showed greater growth rates in phoneme accuracy and word intelligibility than children who received their implants at a later age. Connor et al. (2000) obtained similar results with regard to measures of speech and vocabulary growth as indicated by PPVT scores. Dillon et al. (2012) included the PPVT-III as a measure of vocabulary knowledge in their study of phonological processing in the reading skills of deaf children with CIs. Children aged 6–14 years who had used their implants for 3–12 years obtained a mean standard score of 81 (SD = 19) on the PPVT, where a score of 100 would have indicated vocabularies at age-appropriate levels. Only 3 of the 24 children in the study scored above the median for hearing age-mates. However, PPVT scores were significantly correlated to length of CI use.

Connor, Craig, Raudenbush, Heavner, and Zwolan (2006) pointed out that age of implantation and length of implant use typically are confounded and sought to separate the two with regard to vocabulary and other speech-language variables. They used the PPVT-III in a study involving 100 children who had received CIs between the ages of 1 and 10 years and had used them for up to 13 years. The children were divided into groups according to age of implantation: prior to 2.5 years of age, 2.6–3.5 years of age, 3.6–7 years of age, and 7.1–10 years. Earlier implantation was found to be associated with greater rates of vocabulary growth, with the youngest group showing significantly greater vocabulary growth for the first 3 years after implantation. After 4 years of implant use, however, the rates were essentially the same for all four groups, comparable to the rate of vocabulary growth normally observed in hearing children. Connor et al.’s data did not indicate whether or not the children eventually made up the gap in vocabulary relative to hearing children.

Fagan, Pisoni, Horn, and Dillon (2007) used the PPVT-III in a broader investigation of relations among cognitive, sensory motor, and language measures in deaf 6– to 14-year olds who had received CIs between 1 and 6 years of age. Among a variety of psychological and neuropsychological measures, only the children’s scores on the PPVT and digit span tasks
were found to fall below average compared to hearing peers. Nevertheless, higher PPVT scores were associated with better performance on a variety of reading and memory tests. Fagan and Pisoni (2010) reanalyzed the Fagan et al. (2007) data utilizing hearing age, the length of time the children had used their CIs, rather than chronological age, and found their PPVT scores to fall within the average range. Consistent with previous research (see Luckner & Cooke, 2010), Fagan and Pisoni found broad gaps in the children’s vocabulary knowledge not limited to any particular conceptual or taxonomic category. Although it was not a significant effect, they also noted that the children who had signed prior to receiving their implants had higher PPVT scores than those who did not (see Connor et al., 2000). Related findings were obtained by Wauters, Knoors, Vervloed, and Aarnoutse (2001), who found that deaf children’s accuracy in written word recognition was greater when the words were taught using both spoken and sign language rather than via spoken alone. Hayes, Geers, Treiman, and Moog (2009) administered the PPVT to 65 deaf children who had received CIs prior to 5 years of age and who attended an intensive auditory oral program. Consistent with the Fagan et al. (2007) results, the children scored significantly below hearing peers, but as in the Stelmachowicz et al. (2004) and Connor et al. (2006) studies, there was rapid vocabulary growth after amplification/implantation suggesting that children who receive early amplification might eventually acquire receptive vocabularies comparable to those of hearing peers. At the very least, CIs would be expected to close the vocabulary gap relative to deaf peers without CIs.

The Hayes et al. (2009), Fagan et al. (2007), and Connor et al. (2006) studies raise the possibility that providing young deaf learners with access to spoken language and incidental learning via CIs could allow their vocabularies to catch up to their hearing peers as they get older. Several studies involving high school and college-age students, in contrast, have found CI use unrelated to reading, achievement scores, or classroom learning (Convertino, Marschark, Sapere, Sarchet, & Zupan, 2009; Marschark et al., in press). Further, neither the Radić et al. (2008) study with high school students nor the Sarchet et al. (2014) study with college students found significant differences on the PPVT between the majority of deaf students in their samples and small subgroups that used CIs. Morere (2013a, 2013b) did not report world knowledge results separately for her deaf college students who used CIs, but those students comprised less than 5% of her sample. This study therefore was undertaken to examine explicitly the extent to which CIs contribute to deaf learners’ long-term word and world knowledge. Relatively large samples of deaf college students with and without CIs, together with hearing peers, participated in two experiments. The first examined the effect of CI use on vocabulary knowledge through an extension of the Sarchet et al. (2014) study with the PPVT. The second experiment examined knowledge of the world among deaf CI users as compared to both hearing peers and deaf peers who do not use CIs.

**Experiment 1**

Many of items in the PPVT are not directly represented in the corresponding pictures but require world knowledge in addition to vocabulary knowledge (e.g., that a mushroom is a fungus). Further, many if not most of the items appropriate for college-age individuals do not have lexicalized signs in ASL. Both of these factors may have contributed to Sarchet et al.’s finding that deaf students overestimated their vocabulary knowledge relative to performance when they had to point to pictures corresponding to the stimulus words.

In an effort to “increase access to test item content for students who are deaf or hard of hearing… by altering the way the test item content is presented” (Cawthon, in press), students’ knowledge of PPVT-4 (Dunn & Dunn, 2007) vocabulary in this study was assessed in three different ways. One-third of the students received the picture version of the PPVT used by Sarchet et al. (2014, see below); one-third was asked to select the correct PPVT target word to fit the definition of each word; and one-third was asked to select the correct PPVT target word to fit an appropriate-use sentence. Looking ahead, the latter two alternatives proved more reliable than the original picture version.

**Method**

**Participants.** A total of 274 students participated in the study, all of whom were enrolled at Rochester Institute of
Technology (RIT) and were paid for their participation. These included 89 hearing students, 93 deaf students who used CIs, and 92 deaf students who did not use CIs. The mean reported age of implantation for the students who used CIs was relatively late by current standards (mean = 8.29 years, \( SD = 6.02 \)); the mean length of years of CI use was 13.10 years (\( SD = 5.25 \)).

Within the CI group, there was a subgroup of 25 deaf students who reported receiving their CIs by the time they were 3.5 years of age (mean = 2.56 years, \( SD = .75 \)). The remaining 65 students who reported their age of implantation received them at a mean age of 10.45 years (\( SD = 5.76 \)). Scores on the American College Test (ACT), taken by most deaf students attending RIT, were available from institutional records for 66 deaf students with CIs and 66 without CIs.

**Materials and procedure.** As noted earlier, vocabulary knowledge was assessed in three ways. For all participants, the study involved PPVT-4 \( (\text{Dunn} & \text{Dunn}, 2007) \) vocabulary drawn from Sets 9 (age 10) through 18 (adult). Each PPVT-4 stimulus set contains 12 words, so a total of 120 items was tested for each student. The task as normally administered to hearing individuals involves the examiner saying an English word and having the examinee point to the corresponding target picture on a card containing four alternatives. Because many of the PPVT pictures are not simple referents of words/signs, Sarchet et al. developed a print version of the PPVT administration for use with deaf students. Used here, that “picture version” of the task involves scans of the 120 PPVT stimulus cards in Sets 9–18 placed on PowerPoint slides, completely filling each slide, with an item number (1–120) and the appropriate stimulus word printed in the center in 24-point Calibri. Participants in the present experiment worked through the 120 items in the prescribed order on a tablet, tapping the appropriate response picture on the screen, which was recorded by the tablet.

The “definition version” of the task provided participants with 10 lists, one per page, each containing 12 fill-in-the-blank sentences corresponding to words in a PPVT set. Each sentence was a partial definition for a corresponding word in the set drawn from an online dictionary or similar source (e.g., “Branched horn-like outgrowths from the frontal bones of male deer ______” for “antlers”). Participants were asked to fill in the blank with the word that “best” fit the definition from 18 words listed at the bottom of the page. The 18 words for each set included the 12 correct target words for the set and six pseudowords produced by a pseudoword generator.

The “sentence version” of the task also provided participants with 10 lists, one per page, each containing 12 fill-in-the-blank sentences corresponding to the words in a PPVT set. The sentences were drawn from online dictionaries and similar sources as examples of target word uses (e.g., “In wide open fields we saw a herd of deer, some with huge ______”). Each sentence contained a blank, and participants were asked to fill it in with the word that “best” completed it, selected from the 18 words at the bottom of the page. The 18 words used for each set were the same as in the definition version of the task. The definition and sentence versions of the task can be found in an Appendix accompanying the online version of this paper.

The vocabulary task was administered to each participant by one of two researchers, both of whom also were sign language interpreters with at least 15 years’ experience in the university setting. Instructions were provided in signed and/or spoken language depending on student preference. As students appeared at the laboratory, they were assigned to one of the three conditions semirandomly, seeking only to balance them as closely as possible across the three participant groups.

**Scoring.** For each student, their responses were scored using the method described for the PPVT-4 \( (\text{Dunn} & \text{Dunn}, 2007) \) with Set 9 (age 10) considered the basal set. The last item in the ceiling set (i.e., the last item in the set in which the individual had eight or more correct responses) was the ceiling item. This allowed calculation of a standard score using the students’ birthdates.

**Results and Discussion**

Reliability of the three versions of the PPVT used here was examined via Cronbach alpha analyses involving each student’s proportion of correct items in each of the 10 item sets. For the groups of deaf students with and without CIs, the alphas all were between .94 and .97; in both cases the picture version yielded slightly
lower reliabilities than the other two versions. For the hearing students, reliabilities ranged from .68 for the picture version to .82 for the definition version. Those results are similar to those obtained with the picture version in the Sarchet et al. (2014) study: .89 for their deaf sample and .73 for their hearing sample.

Unless otherwise noted, all and only those results significant at the .05 level or beyond are discussed below. Means and standard deviations for performance by the three groups in the three conditions are provided in Table 1, where it can be seen that there were differences across both groups and conditions. A 3 (group: deaf with CI, deaf No CI, hearing) by 3 (condition: definition, sentence, picture) analysis of variance (ANOVA) indicated that, overall, the group differences yielded a significant main effect of that factor, \( F(2, 265) = 60.68, \text{MSE} = 316.89 \), with Bonferroni post hoc tests indicating that hearing students scored significantly higher than the groups of deaf students with and without CIs, which did not differ significantly from each other. Overall differences among the conditions yielded a significant main effect of that factor, \( F(2, 265) = 9.07 \), with post hoc tests indicating that the sentence version yielded significantly lower scores than the picture and definition conditions, which did not differ significantly from each other (see Table 1).

<table>
<thead>
<tr>
<th>Group condition</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf CI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td>86.77</td>
<td>21.64</td>
<td>31</td>
</tr>
<tr>
<td>Sentence</td>
<td>72.28</td>
<td>20.65</td>
<td>32</td>
</tr>
<tr>
<td>Picture</td>
<td>87.57</td>
<td>17.14</td>
<td>30</td>
</tr>
<tr>
<td>Overall</td>
<td>82.04</td>
<td>20.97</td>
<td>93</td>
</tr>
<tr>
<td>Deaf No CI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td>80.09</td>
<td>22.71</td>
<td>33</td>
</tr>
<tr>
<td>Sentence</td>
<td>71.25</td>
<td>21.61</td>
<td>28</td>
</tr>
<tr>
<td>Picture</td>
<td>82.42</td>
<td>18.10</td>
<td>31</td>
</tr>
<tr>
<td>Overall</td>
<td>78.18</td>
<td>21.22</td>
<td>92</td>
</tr>
<tr>
<td>Hearing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td>109.37</td>
<td>10.17</td>
<td>30</td>
</tr>
<tr>
<td>Sentence</td>
<td>102.21</td>
<td>12.84</td>
<td>29</td>
</tr>
<tr>
<td>Picture</td>
<td>103.83</td>
<td>7.47</td>
<td>30</td>
</tr>
<tr>
<td>Overall</td>
<td>105.17</td>
<td>10.70</td>
<td>89</td>
</tr>
</tbody>
</table>

There was no group by condition interaction, and the condition variable was not considered further.

In order to examine differences among the groups in their knowledge of words appropriate for different ages, the numbers of words correctly identified in each set by students in each group were analyzed using a 3 (group) by 10 (set) ANOVA in which the latter factor was within subjects. Figure 1 reflects the fact that there was both a main effect of group, \( F(2, 271) = 43.73, \text{MSE} = 40.88 \), as the hearing students generally outperformed the deaf students both with and without CIs, and a main effect of set, \( F(9, 2439) = 664.45, \text{MSE} = 2.48 \), as higher scores were obtained for sets with easier words. A significant interaction of those two factors also was obtained, \( F(18, 2439) = 990.98 \). As can be seen in Figure 1, the three groups obtained similar scores on vocabulary appropriate for 10- to 11-year-olds (Sets 9 and 10) but the scores of both groups of deaf students then dropped off relative to those of the hearing group. The two deaf groups showed similar patterns of scores over the 10 sets, with the CI group intermediate between the hearing group and the group of deaf students without CIs.

A correlational analysis examined possible relations among deaf students’ ACT entrance scores, PPVT-4 standard scores, and for participants with CIs, their age of implantation and length of implant use. For students without CIs, PPVT scores were significantly correlated with their ACT reading, English, and total scores, \( r < -.72 < r(64) < .73 \). Neither age of implantation nor years of implant use were significantly related to ACT scores; all of the coefficients were negative and between −1.8 and 0.0. PPVT scores were significantly related to length of implant use, \( r(64) = -.21 \), such that students who used CIs longer had lower vocabulary scores.

Taken together, these results replicate and extend findings previously obtained in studies with DHH children and studies by Radić et al. (2008) and Sarchet et al. (2014) with older students indicating them to have lesser vocabulary knowledge than hearing age-mates as indicated by the PPVT. Offering students alternative ways to demonstrate their vocabulary knowledge (i.e., the definition and sentence versions of the test) did not improve performance. In contrast to the prediction made by Hayes et al. (2009); see also Stelmachowicz...
et al., 2004; Connor et al., 2006), these results suggest that receiving CIs is not sufficient to allow deaf learners to “catch up” to hearing peers in their English vocabulary knowledge or even to surpass nonimplanted peers by college age.

It was noted earlier that as college students, the students with CIs in this study received them relatively late, at a mean age of just over 8 years of age. It thus could be argued that individuals who receive CIs at a younger age and thus use them longer would show greater improvements. Yet, in the present sample, age at receiving an implant was not related to PPVT standard scores, \( r(88) = .06 \). The findings of Connor et al. (2006) cited earlier indicated that after 4 years of implant use, vocabulary growth rates were comparable among groups of children receiving their implants up to 10 years of age. Comparing scores of the subset of 25 students who reported receiving their implants by age 3.5 years (mean length of use = 17.75 years, \( SD = 2.15 \)) with those who reported receiving them later (mean length of use = 11.44 years, \( SD = 5.07 \)) indicated no significant difference in mean standard scores (78 and 84, respectively), \( t(88) = 1.17 \). These results thus indicate that even after 11–18 years of CI use, the PPVT vocabulary scores of CI-using deaf students in this study remained significantly behind those of hearing peers and not significantly greater than nonimplanted deaf peers.

**Experiment 2**

To the extent that vocabulary knowledge is largely acquired incidentally (Hirsch, 2003; Van Zeeland & Schmitt, 2013; Vidal, 2011), or even if it is not, CI use appears to be insufficient for deaf learners, on average, to “catch up” to their hearing peers (Hayes et al., 2009). Students who had received their implants prior to age 4 (Connor et al., 2006) and used them for 15–20 years did not even demonstrate more such knowledge than deaf peers without CIs. While lags in vocabulary knowledge are well-documented among deaf children, the fact that a significant difference remains even among deaf college students suggests that explicit attention to vocabulary acquisition remains important for such individuals.

Vocabulary might be a unique aspect of an individual’s knowledge, however, especially among deaf students, who generally are found to struggle with reading and take longer to read material as well as reading less than their hearing peers (Cawthon, 2011; Marschark, Sarchet, Convertino, Borgna, Morrison, & Remelt, 2012).

Experiment 2 therefore examined other knowledge domains likely to be acquired incidentally to determine how deaf students with CIs compare to those without CIs (and hearing peers) in such knowledge.

Cawthon (in press) noted that because most standardized academic assessments are developed for students who are hearing and who use spoken language, they frequently
contain barriers to DHH students. In Morere’s (2013b) study, for example, although the sentences in the three Woodcock–Johnson III Academic Knowledge subtests were presented to her DHH students via English-based signing, the sentences of that test include a large number of words that do not have sign equivalents and thus would have had to be fingerspelled, replaced with alternative wording, or “explained” via ASL. Taking a different approach here, for the purposes of Experiment 2, alternative assessments of world knowledge were developed in several domains and administered in pencil-and-paper format with minimal literacy demands. Items were created so as to be moderately difficult while avoiding floor and ceiling effects for DHH and hearing college students, what Cawthon (in press) referred to as having “both rigor and equity.”

Method

Participants. All of the students who participated in Experiment 1 also participated in Experiment 2.

Materials and procedure. World knowledge from five different domains was assessed. A History task asked participants to put in order of their occurrence 20, high-visibility world events between the provided end anchors of “1492—Christopher Columbus finds the ‘new world’” and “World Trade Center is destroyed by terrorists” (e.g., the Salem witch trials, Wright Brothers’ first flight, the bombing of Pearl Harbor). A Famous People task asked participants to put the names of 60 famous people into the appropriate categories: actors (e.g., Jack Nicholson), inventors (e.g., Thomas Edison), athletes (e.g., Babe Ruth), or politicians (e.g., Fidel Castro). A Geography task involved identifying 30 U.S. states. Participants were given a map of the lower 48 United States with 30 of them numbered 1–30; highly distinctive states such as Texas and Florida were excluded. The 30 state names were provided in a list, and participants had to match the numbers from the map with the corresponding state names (e.g., Illinois is #______). A Magnitudes task asked participants questions about the weight, size, length, or quantity of 11 real-world things (e.g., the height of a basketball hoop, the weight of a gallon of unbuttered [popped] popcorn). “Just for fun,” an additional question asked participants the weight of a pound of feathers. The above four tasks all were presented in paper-and-pencil format. A fifth, Estimation task asked participants to provide estimates of weight, size, length, or quantity at 11 laboratory stations (e.g., the number of marbles that would fit in a displayed shoebox, the weight of a [filled] five-gallon water jug on a table). Again “just for fun,” an additional question asked students “How many ounces of water are in this 20-ounce bottle?” The question relating to each item was printed and attached to the corresponding station; responses were written on an answer sheet.

The tasks were administered by the same experimenters as an Experiment 1. Instructions were both written and provided in signed and/or spoken language depending on student preference. All tasks were untimed.

Scoring. Because of the accuracy demands of the Magnitude and Estimation tasks, three scores were calculated for each: the proportion exactly correct, the proportion correct within ±10%, and the proportion correct within ±20%. Several aspects of the data on those tasks required special attention: When, contrary to instructions, participants gave ranges rather than exact responses (e.g., 2–4 tons), the midpoint was calculated and used as the response. Similarly, when formulas were given (e.g., the circumference of the laboratory clock as 12π inches), the calculation was performed and the answer used as the response. In addition, there were two situations in which there was doubt about the validity of the data and individual responses were eliminated and treated as missing data. First, outlier answers (e.g., elephants weighing six million pounds or one million pennies fitting into a gallon jug) were left as valid responses if multiple students gave similar responses (e.g., one million pennies fitting into a gallon jug) and otherwise eliminated. Second, when incorrect units were used (e.g., the weight of water given in gallons or the number of apples in a pound given as pounds), responses were eliminated. These latter two situations accounted for less than 0.2% of all responses and were treated as missing data rather than replaced with means.

Results and Discussion

Mean scores on all five tasks are reported in Table 2 as percentages (excluding the “feathers” Magnitude question and “water bottle” Estimation question,
see below). Each task was analyzed using an ANOVA in which group (CI, No CI, hearing) was a between-subjects factor and proportion correct (excluding the above two questions) was the dependent variable. Analysis of the History task data yielded a significant main effect of group, $F(2, 274) = 13.23$, MSE = .03; Bonferroni post hoc tests indicated that the hearing students outperformed deaf students in both the CI and No CI groups, which did not differ from each other. Analysis of the Famous People task yielded the same pattern of results overall: a main effect of group, $F(2, 274) = 24.65$, MSE = .03, with hearing students outperforming students in both deaf groups which did not differ from each other. (Analysis of each of the four categories of famous people revealed the same pattern.)

As can be seen in Table 2, the exact scoring of the Magnitude task was quite low, as each of the groups scored between only 6 and 7% correct and did not differ from each other, $F(2, 274) < 1$, MSE = .004. Analyses of the ±10% and ±20% scores, however, yielded the same pattern of effects as the History and Famous People tasks: a main effect of group, $F(2, 274) = 4.38$, MSE = .006, and $F(2, 274) = 11.38$, MSE = .007, respectively, with hearing students significantly outperforming students in both deaf groups which did not differ from each other according to post hoc tests. Perhaps interestingly, the “pound of feathers” question also yielded the same pattern of effects, $F(2, 274) = 46.04$, MSE = .18. The pattern observed among the three groups (hearing = .97, CI = .53, No CI = .39) might be interpreted as another reflection of incidental learning, as the “pound of feathers” question is not uncommon among hearing people but is not the kind of language play used among deaf signers.

Analyses of Estimation task scores yielded the same pattern of effects described for the other tasks above, with hearing students outperforming deaf students both with and without CIs (not differing from each other) with exact scoring, $F(2, 274) = 11.08$, MSE = .004, as well as with ±10% scoring, $F(2, 274) = 15.23$, MSE = .007, and ±20% scoring, $F(2, 274) = 21.77$, MSE = .008. Perhaps depressingly, the “20-ounce bottle of water” question also yielded the same pattern of effects, $F(2, 274) = 12.49$, MSE = .18. That question aside, although the Estimation task did not tap implicitly acquired factual knowledge, the estimation ability that was required is incidentally learned through socially mediated activities such as games and social interaction (Bull, Marschark, Sapere, Davidson, Murphy, & Nordmann, 2011; Sarama & Clements, 2009). In the most directly related study of which we are aware, Bull et al. (2011) similarly found hearing college students to perform significantly better than deaf college students on a magnitude estimation task (i.e., the number-to-position task of Siegler & Booth, 2004); they did not consider separately students who used CIs.

Finally, the Geography task was the only one that yielded a different pattern of results, as all three groups scored at about the same level (67–73%), with no significant differences among them, $F(2, 274) = 1.67$, MSE = .06. After the fact, it was recognized that what sets this task apart from the others is that being able to identify U.S. states on a map generally is not something

Table 2 Means and standard deviations on five world knowledge tasks for deaf students who use cochlear implants, deaf students who do not use cochlear implants, and hearing students

<table>
<thead>
<tr>
<th>Task</th>
<th>Deaf with CIs</th>
<th></th>
<th>Deaf no CIs</th>
<th></th>
<th>Hearing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>History</td>
<td>.18</td>
<td>.15</td>
<td>.14</td>
<td>.17</td>
<td>.27</td>
<td>.18</td>
</tr>
<tr>
<td>Famous people</td>
<td>.40</td>
<td>.19</td>
<td>.36</td>
<td>.20</td>
<td>.54</td>
<td>.27</td>
</tr>
<tr>
<td>Geography</td>
<td>.73</td>
<td>.24</td>
<td>.67</td>
<td>.25</td>
<td>.69</td>
<td>.24</td>
</tr>
<tr>
<td>Magnitude exact</td>
<td>.05</td>
<td>.06</td>
<td>.05</td>
<td>.06</td>
<td>.06</td>
<td>.07</td>
</tr>
<tr>
<td>Magnitude ±10%</td>
<td>.09</td>
<td>.08</td>
<td>.08</td>
<td>.08</td>
<td>.12</td>
<td>.08</td>
</tr>
<tr>
<td>Magnitude ±20%</td>
<td>.15</td>
<td>.08</td>
<td>.13</td>
<td>.09</td>
<td>.19</td>
<td>.08</td>
</tr>
<tr>
<td>Estimate exact</td>
<td>.05</td>
<td>.06</td>
<td>.03</td>
<td>.05</td>
<td>.07</td>
<td>.07</td>
</tr>
<tr>
<td>Estimate ±10%</td>
<td>.09</td>
<td>.08</td>
<td>.07</td>
<td>.07</td>
<td>.14</td>
<td>.10</td>
</tr>
<tr>
<td>Estimate ±20%</td>
<td>.14</td>
<td>.09</td>
<td>.11</td>
<td>.07</td>
<td>.20</td>
<td>.10</td>
</tr>
</tbody>
</table>
that is acquired incidentally, but is learned explicitly in U.S. schools. As in Experiment 1, on all five of the world knowledge tasks, the subgroup of 25 deaf students who received CIs by 3.5 years of age was compared to the larger group of CI students who received their implants later. None of the differences between those two groups was significant on any of the five world knowledge tasks, all $t(88) \leq 1.89$. As can be seen in Table 3, the trend, if anything, favored the students who received their implants later. Age at implantation was not significantly related to any of the task measures, $-.12 < r(88) < .19$.

A correlational analysis examined possible relations among the deaf students’ ACT mathematics entrance scores and their performance on the Magnitude and Estimation tasks. For students with CIs, their mathematics scores were not significantly related to exact Magnitude scores, $r(64) = .17$, but they were significantly related to the more liberal $\pm 10\%$ and $\pm 20\%$ scores, $r(64) = .29$ and $r(64) = .27$, respectively. Their mathematics scores were significantly related to all three of the Estimation scores, $.30 < r(64) \leq .47$. For students without CIs, none of the correlation coefficients were significant, $.02 \leq r(64) < .21$. The only other relationship that appeared appropriate to examine was that involving the deaf students’ ACT science scores and their scores on the Inventors category of the Famous People task. There was a significant correlation between the scores both for students with CIs, $r(64) = .47$, and those without CIs, $r(64) = .59$. The correlational analyses thus provide some convergent evidence for the validity of the world knowledge tasks, at least for the students with CIs.

### General Discussion

The results of the two experiments described here are easily summarized: Evaluations of word knowledge via the PPVT and world knowledge through a set of pencil-and-paper tasks consistently found a significant difference between hearing college students and their deaf peers. Most relevant for the present purposes, none of the tasks revealed significant differences between deaf students who used CIs and others who did not. Although the scores of the CI group usually were intermediate between the other two groups, the differences between the groups of deaf students were extremely small. Further, the subgroup of the students who had received CIs by 3.5 years of age and used them for 15–20 years performed no better than those who received them later, and neither age of implantation nor length of CI use was related to scores on the PPVT or any of the world knowledge tasks in a positive manner (PPVT scores were inversely related to length of CI use).

This is not the place to lament the frequent perception of poor word and world knowledge among American college students; the popular press does that well enough on a regular basis (Roach, 2006). It is the place, however, to correct another popular (mis-)perception, that CIs fully close the language gap between deaf learners and their hearing peers. There is no doubt that CIs allow more deaf children than ever before to

### Table 3

Means and standard deviations on five world knowledge tasks for deaf students using cochlear implants who received them by 3.5 years of age ($N = 25$) or later ($N = 65$)

<table>
<thead>
<tr>
<th>Task</th>
<th>Deaf with CIs received ≤3.5 years</th>
<th>Deaf with CIs received &gt;3.5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>History</td>
<td>Mean: .15, SD: .15</td>
<td>Mean: .18, SD: .14</td>
</tr>
<tr>
<td>Famous people</td>
<td>Mean: .39, SD: .15</td>
<td>Mean: .40, SD: .20</td>
</tr>
<tr>
<td>Geography</td>
<td>Mean: .74, SD: .26</td>
<td>Mean: .72, SD: .24</td>
</tr>
<tr>
<td>Magnitude exact</td>
<td>Mean: .04, SD: .05</td>
<td>Mean: .06, SD: .09</td>
</tr>
<tr>
<td>Magnitude ±10%</td>
<td>Mean: .07, SD: .06</td>
<td>Mean: .09, SD: .08</td>
</tr>
<tr>
<td>Magnitude ±20%</td>
<td>Mean: .12, SD: .08</td>
<td>Mean: .16, SD: .09</td>
</tr>
<tr>
<td>Estimate exact</td>
<td>Mean: .04, SD: .06</td>
<td>Mean: .06, SD: .06</td>
</tr>
<tr>
<td>Estimate ±10%</td>
<td>Mean: .09, SD: .07</td>
<td>Mean: .09, SD: .08</td>
</tr>
<tr>
<td>Estimate ±20%</td>
<td>Mean: .13, SD: .08</td>
<td>Mean: .14, SD: .09</td>
</tr>
</tbody>
</table>
acquire some hearing and speech, but rarely does either reach the levels of hearing age-mates. From an educational rather than an audiological perspective, a frequently suggested benefit of CIs has been that by giving deaf children the ability to overhear the language of others, they are likely to gain larger language repertoires. Greater access to language, in turn, is assumed to benefit language-acquired knowledge of the world that facilitates cognitive development (e.g., executive functioning), social-emotional functioning (e.g., theory of mind), and literacy skills (e.g., vocabulary). To the best of our knowledge, however, research has not yet demonstrated a direct link between better hearing and incidental learning among deaf individuals with CIs as compared to those without CIs.

Connor et al. (2006) and Hayes et al. (2009) observed accelerated vocabulary learning among children who had received CIs, rates comparable to those of hearing age-mates. Hayes et al. (2009) suggested that such increases might allow children with early, significantly aided hearing to catch up to hearing peers as they get older. Relatedly, Moog and Geers (2003), McConkey Robbins (2006), and others have emphasized CIs as a gateway to incidental learning with broad developmental implications. These results, in contrast, indicate that whatever incidental learning enhancement was provided to the deaf participants through CIs was not sufficient to provide them with either word or world knowledge significantly beyond deaf peers without CIs. This conclusion warrants two caveats: First, the present sample of deaf learners was limited in the sense that age of implantation for these individuals was relatively late compared to children who are now receiving implants at 12 months of age and younger (in the United States, cochlear implantation for children younger than 2 years of age was not approved until 2000). Stith and Drasgow (2005) pointed out that many later-implanted deaf children would not have the incidental learning skills necessary to take advantage of language in the environment and might need strategic training in that regard. Second, the present sample also was limited in the sense that it consisted of deaf students who had gained entry to college, and thus would be expected to have greater word and world knowledge as well as more effective learning strategies than deaf peers in the general population (Allen, 1994).

Although CIs generally have been found to be associated with better reading comprehension among young deaf children (Geers, Tobey, Moog, & Brenner, 2008), other outcomes are extremely variable, variability that is largely unexplained and frequently ignored (Niparko, Tobey, et al., 2010). Further, implant use has not been found to be associated with academic performance among high school and college students (Convertino et al., 2009; Marschark et al., in press).

This study in no way undermines the potential benefit of CIs for deaf children. There is now sufficient evidence to indicate that most deaf children who receive CIs benefit from the enhanced hearing provided by that technology both directly and indirectly. What the present findings emphasize is that CIs generally do not provide sufficient hearing to allow deaf children full access to language and other information in the environment. These results consistently indicated that deaf students with CIs were not performing significantly better than peers without CIs with regard to their word knowledge or their world knowledge. Their opportunities for incidental learning through audition and cumulative knowledge acquisition may surpass those of peers without CIs, but a domain in which such knowledge can be attributed to overhearing the language of others has not yet been demonstrated. At the same time, the results from the Geography task in Experiment 2 clearly indicate that deaf students with and without CIs can acquire world knowledge comparable to their hearing peers when that information is taught explicitly, and the same is true in a variety of other knowledge domains (see Marschark, Sapere, Convertino, & Pelz, 2008, with regard to psychology, mathematics, and computer science). If nothing else, the present findings thus suggest that if they are to benefit fully from the opportunities offered by their CIs, deaf children who use them need to be taught in a way that both builds on their strengths and accommodates their needs rather than assuming that they function the same as hearing classmates.

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Conflicts of Interest

No conflicts of interest were reported.

Notes

1 “English” is intended generically here to refer to any spoken/written vernacular. See Rinaldi, Caselli, Onofrio, and Volterra (2014) for evidence concerning deaf children’s total vernacular + sign language vocabularies.

2 History also is learned explicitly in school, but the relative ordering of historical events over the range considered here is learned implicitly.

References


